Army Research Laboratory

Battlescale Forecast Model Sensitivity Study

by Barbara Sauter, Teizi Henmi, and Edgar Pedregó

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Battlescale Forecast Model Sensitivity Study

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Background

During 2001, the ARL Battlefield Environment Division participated in the Weather Web aspect of the Smart Sensor Web program sponsored by the Office of the Secretary of Defense. Under this program, a Small Business Innovation Research contract was put in place to develop expendable weather sensors for the battlefield. The Army intelligence community has specified desired accuracies for various meteorological parameters on the battlefield, both as measured observations and as forecast values. However, no answer was readily apparent when one of the SBIR contractors asked how much a change in a surface measurement affected a forecast based on a model initialized with the surface observation. Therefore, this study was undertaken to provide a limited answer to the question: "How sensitive is the Battlescale Forecast Model (BFM)[1] to inaccuracies in the surface observations used in its initialization?"

Approach

The approach taken to study the BFM sensitivity to inaccuracies in surface observations used in the model initialization was based on applying resources already on hand. Model runs were performed over Oklahoma, since all the required files for model execution, terrain, surface observations, and Navy Operational Global Atmospheric Prediction System (NOGAPS) data were available from a previous nowcast research effort[2]. An existing task order on the New Mexico State University Physical Science Laboratory (PSL) contract funded by the Weather Web project specified requirements that had become obsolete after the Lincoln Lab Weather Web test bed was abandoned. The statement of work on the task was modified for the student at PSL to perform the numerous model runs using actual and modified surface observations for 12 stations and comparing the resulting forecast of basic parameters for the remaining 90 stations.

[1] Henmi, T.; Dumais R., Description of the Battlescale Forecast Model. Technical Report ARL-TR-1032, U.S. Army Research Laboratory, WSMR, NM, 1998.

[2] Sauter, B.; Henmi T.; Dumais R., Comparing Nowcasting Methods Using Oklahoma Mesonet Data. Proceedings of the Battlespace Atmospheric and Cloud Impacts on Military Operation (BACIMO) Conference 2001, July 2001.

Executive Summary

Results

One parameter at a time was modified by the identical amount for all 12 input surface stations in the initialization files, including temperature by ± 4°C and ± 2°C, relative humidity by –40 percent and –20 percent, wind speed by ± 5 kn and ± 2.5 kn, and wind direction by ± 60° and ± 30°. In this study, these changes to the surface observations used in the BFM initialization led to no significant changes in the resulting values for hourly forecasts from the initialization time of 12Z through a 6-h forecast of temperature, relative humidity, wind speed, or wind direction. The report discusses some differences, but the magnitudes involved are very much less than the accuracies of the measurements involved. Some information on the forecast accuracies using the original surface observations is also provided.

1. Introduction

The military often operates in locations without standard meteorological observations at the time and space scales desired. Development efforts investigating weather sensors for the battlefield include a requirement for expendable systems. Whether such systems were hand-emplaced by soldiers or air-dropped from low aircraft, the sensors could not be expected to conform to normal weather sensor placement and accuracy standards. The purpose of this study was to investigate the impact of errors in surface measurements on a model forecast initialized with the inaccurate observations.

2. Methodology

The Battlescale Forecast Model (BFM) (*1*) was run over a 600 km by 400 km domain over Oklahoma, encompassing 102 surface stations in the Oklahoma mesonet (fig. 1.) Boundary conditions were obtained from the Navy Operational Global Atmospheric Prediction System (NOGAPS) (*2*) model output. The BFM was initialized at 12Z using the NOGAPS 12Z analysis and 00Z forecast data fields along with 12 surface station observations at 12Z. Output consisted of hourly forecasts of temperature, relative humidity, wind speed, and wind direction from 12Z through 18Z, including a 0-h through a 6-h forecast. These baseline forecasts were generated for 20 winter and 20 summer days, based on data from consecutive days in late January and February 2000 and from every third day in May and June 2000.

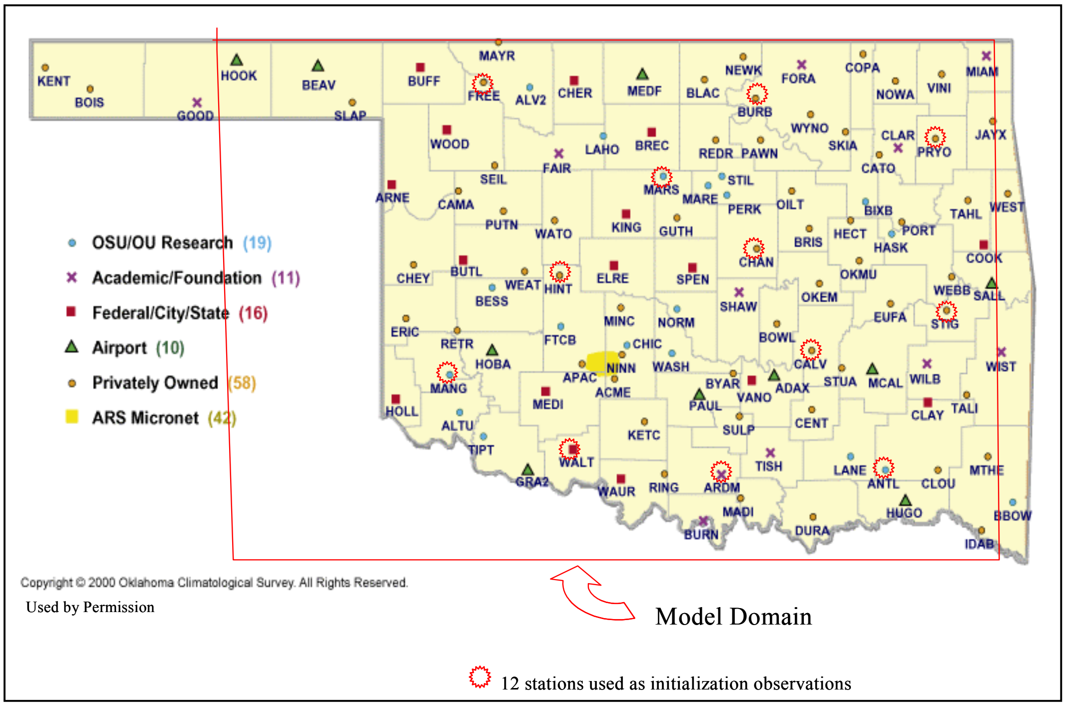

Figure 1. BFM model domain with Oklahoma mesonet stations.

The identical days used for the baseline forecasts with actual surface observations were run with modified surface data files, incorporating a specific change to a single parameter at a time to all 12 surface station observations. The various errors introduced into the surface observations are summarized in table 1. The changes in relative humidity are values given in percent as the measurement unit, but modifications are whole increments, such that a "-20 percent" change would take an original observation at 85 percent relative humidity and transform it to 65 percent relative humidity. The modifications did not involve raising the relative humidity to a higher value because many original relative humidity observations were close to 100 percent.

Table 1. Modifications to original surface observations

Parameter	Modification Amounts			
Temperature	+ 4 ° C	+ 2 ° C	- 2 ° C	- 4 ° C
Relative humidity			- 20 %	- 40 %
Wind speed	+ 5 m/s	+ 2.5 m/s	- 2.5 m/s	- 5 m/s
Wind direction	+ 60°	+ 30°	- 30°	- 60°

Effects of the modification of each particular parameter on all the parameters forecast were analyzed. This analysis was used to determine the sensitivity of the BFM to inaccuracies in particular surface sensors. In order to simplify the analysis, modifications were always biased by the same amount in the same direction for all 12 stations used as input by the BFM. Statistics were generated by season and forecast hour comparing the forecasts for the remaining 90 stations after modifying the input surface observations (the modified forecast) with the original forecast for the 90 stations using the original surface observations (the baseline forecast.) These results are discussed in the next section. Finally, some information is provided on the BFM accuracy comparing the baseline forecasts with the actual observations at the 90 stations.

3. BFM Sensitivity Results

This particular study showed no sensitivity whatsoever of the BFM to changes in surface observations used in model initialization. Purposely introducing substantial errors in temperature, humidity, or wind measurements led to no change in the resulting forecast values or in changes much smaller than the variation expected from the limited accuracy of the parameter, whether as a measurement or a forecast value. Although the following discussions detail some of the results of this study, it is important to note that the differences are totally insignificant in operational terms. The statistics are based on averaged values for the 90 stations averaged separately for each forecast hour over the 20 days in winter and 20 days in summer. Table 2 relates the maximum absolute value of this average difference between the baseline forecast value and the modified forecast value.

Temperature and relative humidity forecasts are most affected by modifying the input value of the corresponding parameter. However, wind forecast impacts are similar whichever input parameter is modified.

Table 2. Greatest average absolute difference between baseline and modified forecast values.

Modified Parameter	Forecast Parameter			
	Temperature (° C)	**Relative Humidity (%)**	**Wind Speed (m/s)**	**Wind Direction (deg)**
Temperature	.07	.25	.04	1.1
Relative humidity	.01	.80	.03	0.9
Wind speed	.01	.03	.04	0.8
Wind direction	.03	.03	.02	0.8

3.1 Modified Temperature Observations

Army users have specified a requirement for temperature measurements and forecasts to be accurate within 1 °C (*4*). With the original NOGAPS and other surface parameter data, the 12Z temperature values for the 12 input surface stations were each increased by 4 °C, then used in the BFM initialization for all the model runs. These runs were repeated with the input surface temperatures raised by 2 °C, as well as lowered by 2 °C and 4 °C.

Figure 2 shows a sample timeline chart for the mean difference between modified and baseline temperature forecasts for each hour. Positive values result when the modified forecast value is greater than the baseline forecast value, while negative values mean that the modified temperature forecast was less than the corresponding baseline temperature forecast.

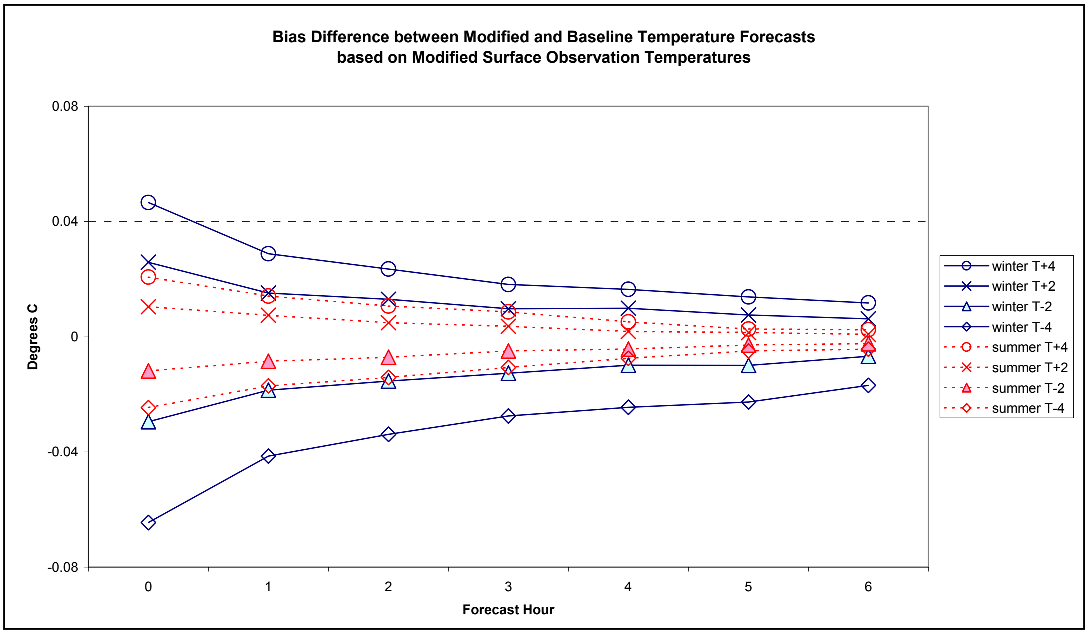

Figure 2. Sample timeline chart of mean difference (bias) between modified and baseline hourly temperature forecasts.

As expected, the modified temperature forecasts varied in the same direction as the modified surface observation, so raising the temperature of the stations used in model initialization raised the forecast temperatures of the other stations, although to a much smaller extent than the original modification. The bias error amount is usually the same as the absolute error amount, because any changes in station forecasts are almost always in a single direction.

Other results seen from modifying the original temperatures in the initialization stations include:

- Winter forecasts contain greater impacts than summer forecasts.
- The 0-h forecast is most affected for modified temperature and relative humidity forecasts, as well as for wind forecasts in the summer.
- The 1- and 2-h forecasts are most affected for modified wind forecasts in the winter.
- Increasing original temperatures results in increased relative humidity forecasts for 0- and 1-h forecasts but causes slightly decreased relative humidity forecasts for 3- through 6-h forecasts in the winter.

- Increasing original temperatures results in increased wind speed.
- Decreasing original temperatures causes changes equal in size but opposite in direction from increasing original temperatures.

3.2 Modified Relative Humidity Observations

As mentioned in the discussion on the methodology of this study, original relative humidity observations at the 12 input stations were modified to lower values only, with all 12Z surface station relative humidity observations used in model initialization decreased by 20 percent for one set of modified model forecasts and by 40 percent for the second set.

Minor effects seen from modifying the original relative humidities in the initialization stations include:

- Winter forecasts of temperature and relative humidity contain greater impacts than summer forecasts.
- Summer forecasts of wind speed and direction show greater impacts in the 4- through 6-h forecasts than in the winter.
- Temperature forecasts contain a bias toward increased temperature for the 0-h forecast and decreased temperature for 1- through 6-h forecasts.
- The total absolute difference between the modified temperature forecast and the baseline temperature forecast grows throughout the forecast hours 2 through 6 in the summer model runs, contrary to what might be expected.
- The modified relative humidity forecasts are most changed in the 0-h forecast with close to no impact in subsequent hours.
- Modified wind direction forecasts do not reflect a change in any particular direction when the original relative humidity is lowered, but the total absolute difference grows slightly from hour 2 to 6, with an unexplained drop at hour 5.

3.3 Modified Wind Speed Observations

The wind speed values were changed by amounts approximately equal to the documented Army requirement for wind speed accuracies within 5 kn (*3*), as well as by twice this amount, with model runs performed using wind speeds increased by 2.5 and 5 m/s and decreased by the same amounts. Figure 3 shows an example timeline chart of the absolute difference in modified temperature forecast values compared to baseline temperature forecasts for each of the four modifications to the original wind speed values.

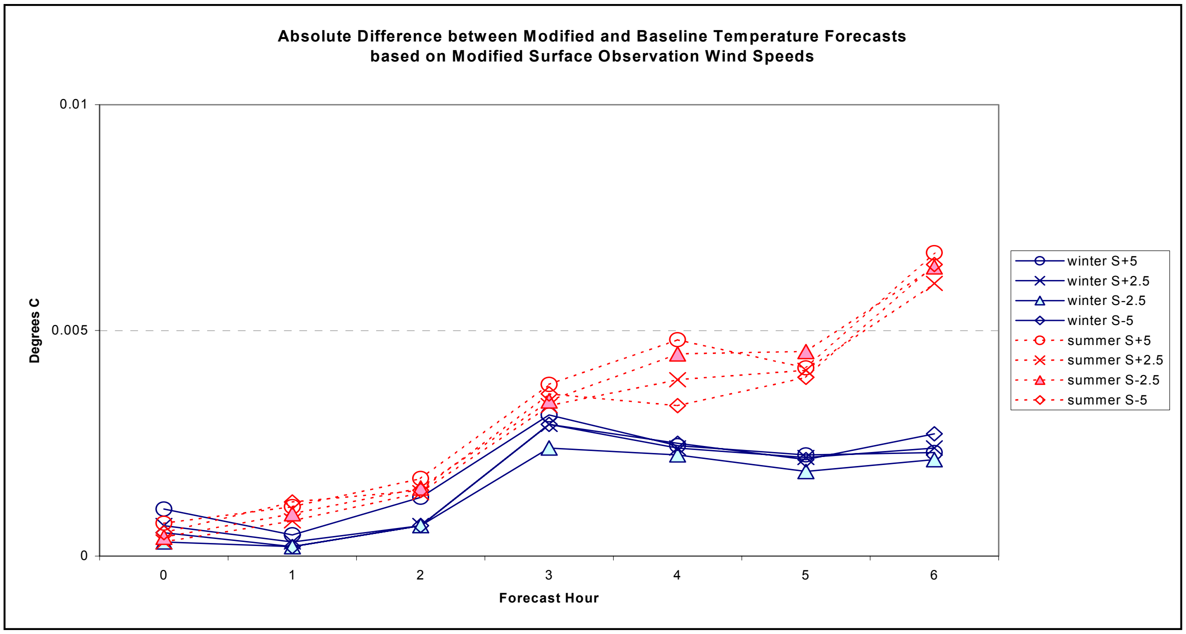

Figure 3. Sample timeline chart of absolute difference between modified and baseline hourly temperature forecasts.

The effects of modifying wind speeds at hour 0 become increasingly greater on temperature forecasts as the forecast times increase from hour 1 to 6, particularly for the summer runs. It is important to remember, however, that even the largest impact is much too small to be meaningful.

Other results based on modifying wind speeds include:

- The mean differences in the modified temperature forecasts show no bias for increasing or decreasing the temperature, whether the wind speeds were increased or decreased.
- Increasing or decreasing the initializing wind speeds changed the 0-hour wind speed forecasts in the same direction, without a similar bias in subsequent forecast hours.

- The differences between the baseline and modified wind direction forecasts do not form a well-defined pattern but are generally greatest at the 0 hour, with another spike at the 5-h forecast in the summer.

3.4 Modified Wind Direction Observations

Surface wind directions for the 12 initializing stations were modified by +60° and +30° (clockwise) and -30° and -60° (counterclockwise).

Trends seen in the results based on modifying wind directions include

- The impact on modified wind direction forecasts is greater in the winter for the 0- through 3-h forecasts but greater in the summer for the 4- through 6-h forecasts.
- Modified temperature and relative humidity values show no bias toward increased or decreased values throughout the forecast period, although the absolute differences grow larger as the times progress from the 0- h through the 6-h forecasts.
- The modified 0-h wind speed forecasts show a bias toward decreased wind speeds for wind direction changes in both directions.
- Modified wind direction forecasts vary in the same direction as the modified initializing wind directions for hours 0 through 2, but reflect a positive (clockwise) bias in hours 3 through 6 for both positive and negative changes in the initial wind directions.

4. BFM Accuracy Results

The purpose for this study was to investigate changes in the model forecast based on changes in the surface station observations used in model initialization. However, the baseline results also provide information on the accuracy of the BFM forecast compared to the station observations not used in the initialization. This information is based on the baseline methodology described in section 2, using actual surface observations from 12 stations over 20 days in the summer and 20 days in the winter in BFM runs to generate baseline forecasts for 90 stations, not including the original 12. These forecasts are then compared to the actual observations taken at the 90 stations.

4.1 Temperature Forecast Accuracy

Figure 4 includes the mean difference (bias) and absolute difference between temperature forecasts and observations for the winter and summer periods for each forecast hour. The errors are much greater than the 1 °C accuracy desired by the Army.

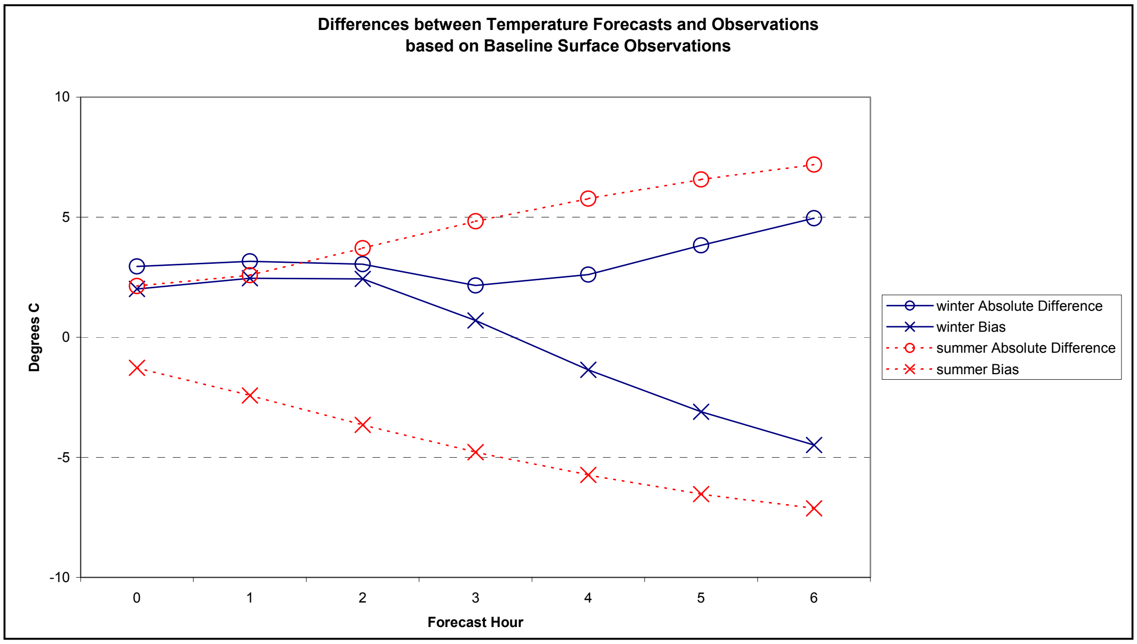

Figure 4. Baseline temperature forecast accuracy by forecast hour.
Note: Negative bias when forecast is too low.

The temperature forecast results include the following:

- The winter temperature forecasts include a warm bias in hours 0 through 3 and a cold bias in hours 4 through 6.
- The summer temperature forecast absolute error amount is quantitatively the same as the bias amount, with temperature forecasts in the summer consistently too low.
- Absolute temperature errors range from approximately 3 °C at hour 0, growing to 5 °C in the winter and 7 °C in the summer at hour 6.

4.2 Relative Humidity Forecast Accuracy

Figure 5 includes the mean difference (bias) and absolute difference between relative humidity forecasts and observations for the winter and summer periods for each forecast hour. The observed relative humidities tended to be almost uniformly high in the 80–100 percent range at the 0-hour forecast valid at 12Z or 6 a.m. local standard time, but much more varied and generally significantly lower by the 6-h forecast.

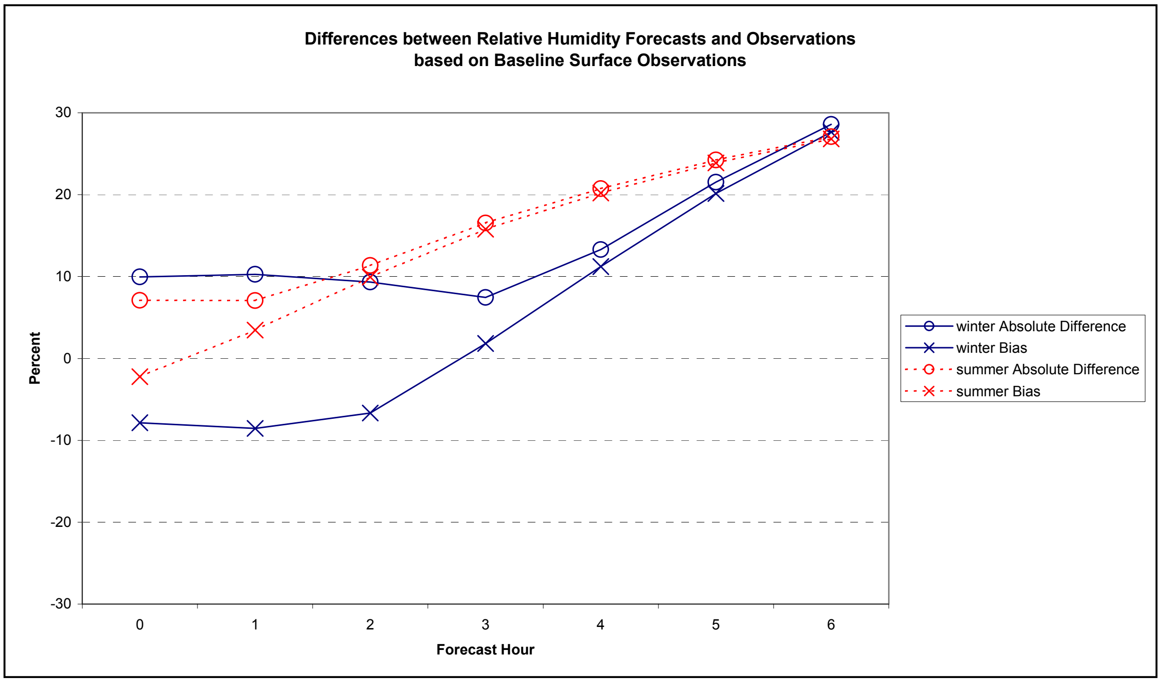

Figure 5. Baseline relative humidity forecast accuracy by forecast hour.
Note: Negative bias when forecast is too low.

The relative humidity forecast results include the following:

- Relative humidity forecast errors were close to 10 percent for hours 0 through 2, with a bias toward too low relative humidity forecasts for these hours in the winter, but only a slight low bias at hour 0 in the summer, with increasing positive biases throughout the remaining forecast times.
- Relative humidity forecasts did not accurately reflect the significant decrease in relative humidity by late morning/noon, when both summer and winter forecasts overestimated relative humidity by 20 to almost 30 percent.

4.3 Wind Speed Forecast Accuracy

Figure 6 includes the mean difference (bias) and absolute difference between wind speed forecasts and observations for the winter and summer periods for each forecast hour. The wind speed errors are close to the 1 m/s accuracy desired by the Army for the initial forecast times but in general do not meet the requirement.

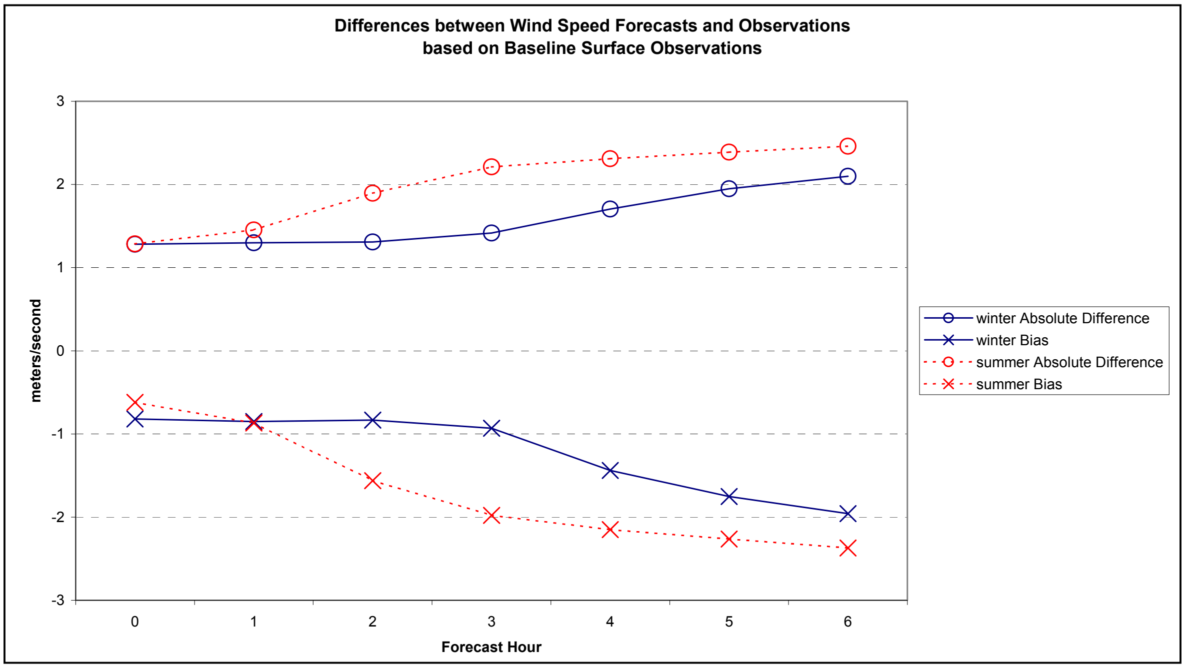

Figure 6. Baseline wind speed forecast accuracy by forecast hour.
Note: Negative bias when forecast is too low.

The wind speed forecast results include the following:

- Mean wind speed forecasts for the validation stations reflect a negative bias at each forecast time for both winter and summer model runs.
- Wind speed errors range between 1 and 1.5 m/s during hours 0 through 3 in the winter, growing to 2 m/s by the 6-h forecast.
- Wind speed errors in the summer are close to those in the winter for the 0-h forecast, but grow faster to 1 m/s by the 2-h forecast, reaching approximately 2.5 m/s at the 6-h forecast.

4.4 Wind Direction Forecast Accuracy

Figure 7 includes the mean difference (bias) and absolute difference between wind direction forecasts and observations for the winter and summer periods for each forecast hour. The errors substantially exceed the 5° accuracy desired by the Army, but these mean values include light and variable wind situations.

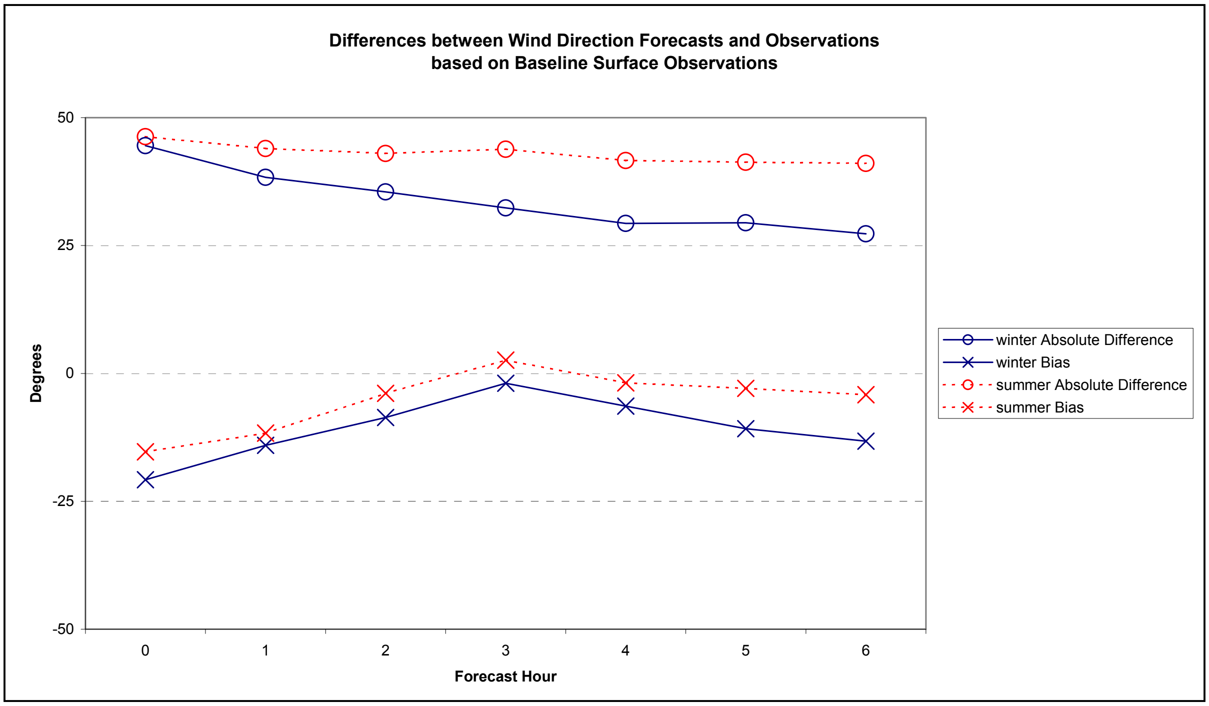

Figure 7. Baseline wind direction forecast accuracy by forecast hour.
Note: Negative bias when forecast is from a direction counterclockwise from the observed direction.

The wind speed forecast results include the following:

- Unlike the other forecast parameters, wind direction absolute errors actually decrease as the forecast times go out, possibly because large errors are associated with the more prevalent light and variable winds in the early morning hours close to hour 0.
- Wind direction forecasts are generally biased in the negative direction, indicating that the observed wind is actually from a more clockwise direction, although the 3-h forecast contained close to no bias in wind direction.

- Absolute wind direction errors ranged from greater than 40° at hour 0, decreasing only slightly by hour 6 in the summer, but decreasing to near 25° in the winter.

5. Conclusions

This study was initiated in response to the question, "How much do inaccuracies in surface measurements affect the BFM output?" To answer this question, changes were purposely introduced in the surface station observations used in model initialization. One parameter at a time was modified with changes larger than any expected sensor inaccuracy. There were absolutely no significant changes in the resulting model forecast of the changed parameter or other basic parameters.

The surface parameters used included temperature, relative humidity, wind speed, and wind direction, which are all used in the BFM initialization. The study was limited to one location and one initialization time over two seasons, totaling 40 baseline model cases with output for 90 stations used in the comparisons. Although these results might not be representative of other times or places, the Oklahoma mesonet stations used seem more likely to have shown impacts resulting from the modified surface observations than some other locations containing more variability due to terrain or coastal effects. Purposely incorporating surface observation errors at an afternoon initialization time rather than the early morning might lead to greater impacts in the resulting forecast, but they would have to be very much greater to exceed the amount of uncertainty already occurring in any weather forecast.

These cases also highlighted the large uncertainty potentially associated with model weather forecasts in general, since the accuracy of the basic parameters forecast was often insufficient for Army needs.

6. Recommendation

When local data is desired for battlefield model initialization, emphasis should be placed on obtaining a local upper-air profile rather than just surface observations. When surface sensors are available in an area of operations, the Army users should be provided the actual measurement information and not just resulting forecast data incorporating the surface measurements.

References

1. Henmi, T.; Dumais R.: *Description of the Battlescale Forecast Model*. Technical Report ARL-TR-1032, U.S. Army Research Laboratory, WSMR, NM, 1998.

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3. Weather Support Team, U.S. Army Intelligence Center: *Weather and Environmental Data Element Requirements*. Internal Report, Futures Directorate, Fort Huachuca, Arizona, May 1998.

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12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Expendable sensors might be used on the battlefield to report weather data not in conformance with normal weather sensor placement and accuracy standards. The purpose of this study was to investigate the impact of errors in surface measurements on a model forecast initialized with the inaccurate observations. Changes to the surface observations used in the Battlescale Forecast Model initialization led to no significant changes in the resulting forecast values of temperature, relative humidity, wind speed, or wind direction. Some information on the forecast accuracies using the original surface observations is also provided.

15. SUBJECT TERMS

BFM, Battlescale Forecast Model, surface observation, model sensitivity, forecast accuracy

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